

Technical Memorandum

*Development of a Micro Inventory of
Air Pollutant Emissions for
Grand Canyon National Park, Arizona*

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October 1994

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October 7, 1994

SUMMARY OF SIGNIFICANT FINDINGS

Radian developed an air pollutant micro emissions inventory for Grand Canyon National Park (the Park). This inventory will be used by the Grand Canyon Visibility Transport Commission to assess visibility-emission relationships on a local scale in and near the Park. Several potentially important findings result from this effort:

- On a county-wide basis, the Park does not add appreciably to the Coconino County totals. Emission densities in the Park, however, are up to an order of magnitude larger than the emission densities currently being used by the Commission for regional scale modeling.
- Aircraft and recreational boating for Coconino County appear to be significantly underestimated. Sightseeing by air and water is a highly popular activity in the Park that is not well represented in the Commission Inventory.
- Mobile sources (on-road, recreational boating, and aircraft) are the predominant emission source categories in the Park.
- Wildfire emissions were tabulated for a seven year period (1986-1992) using the USDA Forest Service Wildfire database. The peak fire year occurred in 1989, when EC_{2.5} and OC_{2.5} emissions from wildfires exceeded the Park micro inventory anthropogenic emissions by a factor of two. No wildfires greater than 100 acres occurred from 1990 through 1992.
- In none of the five years (1989-1993) for which prescribed fire emissions were computed did EC_{2.5} or OC_{2.5} emissions exceed more than 50% of the Park micro inventory totals.

1.0

INTRODUCTION

This report documents an air pollutant emissions inventory for Grand Canyon National Park (the Park). This inventory was funded by, and developed jointly for, the Grand Canyon Visibility Transport Commission (through the Western Governor's Association) and the Electric Power Research Institute (through Project VARED). The inventory covers emissions from the South Rim (Grand Canyon Village and Desert View), the North Rim, the inner canyon, and sightseeing aircraft. It was developed to help assess the potential influence of local emissions on visibility in the Park.

The inventory is a local, or micro inventory. It was developed with site-specific information on the sources of air pollutant emissions in the Park and the operating characteristics and activity of these sources. This operating information, called activity data, was collected at the Park by the National Parks Service (NPS). Organizations providing data for use in this inventory include the NPS, USDA Forest Service, U.S. Postal Service, and concessionaires on both the South Rim (Fred Harvey Company) and North Rim (TW Recreational Services, Inc.). Radian and NPS jointly chose 1993 as the base year for the micro inventory because more activity data were available for this year than any alternative year.

Park visitation has increased steadily over the past several years. Figure 1 illustrates the monthly visitation to the Park since March 1991. There is clearly an upward trend in visitation, in addition to the normal seasonal fluctuation. Peak summer visitation is currently over 800,000 visitors a month. When considered on a daily basis, and including permanent staff and summer help, the daily summer "population" of the Park is approximately 25,000, which would make it the second largest "city" in Coconino County after Flagstaff.

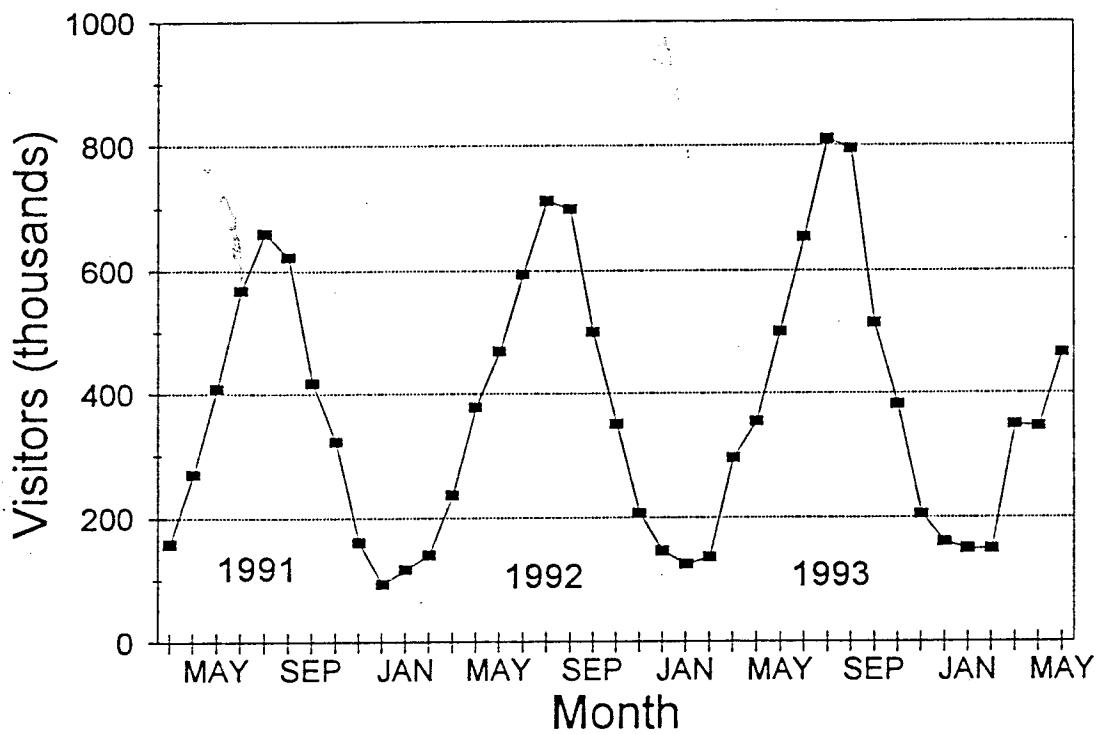


Figure 1. Monthly Visitation at Grand Canyon NP

2.0

INVENTORY RESULTS

Table 1 presents the results of our micro inventory for the Park for the nine pollutants for which we estimated emissions: sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), fine particulate matter less than 2.5 micrometers in diameter ($\text{PM}_{2.5}$), organic carbon fine particulate matter ($\text{OC}_{2.5}$), elemental carbon fine particulate matter ($\text{EC}_{2.5}$), particulate sulfate (SO_4), total particulate matter (TSP), and volatile organic compounds (VOC). The emissions in Table 1 are presented for the four areas in the Park for which we estimated emissions: South Rim, North Rim, commercial aircraft tours in the Federal Aviation Administration (FAA) special flight rules area (SFAR) above the Park, and commercial motorboat tours on the Colorado River. Most of the emission sources in the Park are located in or near Grand Canyon Village on the South Rim.

Table 1**Grand Canyon National Park Micro Inventory Emissions by Area, 1993**

Location	Average Annual Emissions (ton/year)								
	SO_x	NO_x	CO	$\text{PM}_{2.5}$	$\text{OC}_{2.5}$	$\text{EC}_{2.5}$	SO_4	TSP	VOC
North Rim	4.8	22.8	188	67.8	3.3	0.41	0.06	67.8	23.4
South Rim	44.7	305	1,790	1,910	91.4	12.1	0.98	1,910	246
Aircraft	6.5	84.4	1,130	6.6	0.67	1.8	0.24	16.9	69.1
Along River	2.9	8.6	1,600	21.3	10.7	4.8	0.76	47.3	868
Total*	59	420	4,700	2,000	110	19	2.0	2,000	1,200

* Emission totals are rounded to two significant figures.

Table 2 presents a comparison of the micro inventory results with the larger-scale emissions inventory for Coconino County, Arizona, the county in which most of the Park is located. (For ease of reading, Table 2 and all succeeding tables are presented following the text.) Emissions in Table 2 are listed by 10-digit area source category code (ASCT). The Coconino County emissions are for a 1990 base year and are from the Grand

Canyon Visibility Transport Commission inventory. The Commission inventory for these sources is based upon the 1990 U.S. Environmental Protection Agency (U.S. EPA) Interim Inventory.

On a county-wide basis, the Park does not add appreciably to the Coconino County totals. However, emissions from aircraft and recreational boating appear to be significantly underestimated in the Commission emission totals for Coconino County. The most significant emission sources in the Park are mobile sources (on-road vehicles, aircraft, and recreational boating).

3.0 INVENTORY METHOD

The NPS conducted an exhaustive search for potential emission sources within the Park. As a result of their extensive activity data collection efforts, NPS was able to provide activity data for 18 area source categories for which we subsequently estimated emissions. Table 3 presents a brief description of these 18 source categories and the methodology used to estimate emissions. For each source type, Table 3 also provides a brief description of the activity data producing, or associated with, the emissions.

We examined other potential emission sources not included in Table 3. Table 4 presents a description of 11 additional area source categories examined and the reason for not including the source category in the inventory. For example, there is a small refuse incinerator on the South Rim for burning waste from the medical clinic. However, this incinerator operates only a few hours per year and has not operated since 1991. Consequently, incinerator emissions were not quantified for this 1993 inventory.

Emission estimates for wildfires (forest fires) and prescribed burning are not presented in either Table 1 or Table 2 because these two source categories are not well represented by yearly average emission values. There is considerable variation from year to year in the number of fires and the amount of emissions that occur. Consequently, a year-to-

year presentation of the emission totals provides a clearer representation of wildfire and prescribed burning emissions in the Park. Table 5 presents yearly emission estimates for wildfires that consumed more than 100 acres in the Park for the years 1986 to 1992. The episodic nature of fires is very evident; there were no wildfires of greater than 100 acres for the years 1990 to 1992. The data in Table 5 were provided by the USDA Forest Service (Mr. Peter Lahm). For the peak fire year (1989), OC_{2,5} emissions from wildfires exceeded the micro inventory total for the Park by more than a factor of two. Appendix A provides more detail on the wildland burning emission calculation methodology.

Radian estimated prescribed fire emissions based upon data provided by the USDA Forest Service. Table 6 presents prescribed fire emission estimates for the Park for the years 1989 through 1993. There is considerable variation in the acreage burned each year, from a low of zero in 1991 to a high of approximately 2,300 acres in 1993. In none of the five years for which Radian estimated prescribed fire emissions did the EC_{2,5} or OC_{2,5} emissions exceed more than 50% of the Park micro inventory totals.

The micro inventory for the Park is a stand-alone inventory and it should not be added to the Commission inventory. To combine the two inventories would result in a potential over-estimate of emissions because of the resultant double counting of specific sources in both inventories. Table 7 presents our assessment of the potential for double counting for each of the 18 source categories for which we estimated emissions.

Copies of the spreadsheet pages used to estimate emissions for the Park are given in Appendix B.

4.0 GRIDDED EMISSIONS

The NPS plans to perform visibility modeling using the micro inventory. Consequently, we gridded the micro inventory using the Commission air quality modeling grid system. The Commission grid is a rectangular grid with an approximate grid cell side

length of 50 kilometers (km). The air quality modeling being done for the commission assumes a uniform emissions density within each grid cell.

Table 8 presents the gridded emissions for the seven grid cells that intersect the Park boundaries. Grand Canyon Village on the South Rim lies in cell X-cell 33, Y-cell 21. Most of the Park activities and, hence, most of the emissions occur in this cell. However, commercial aircraft flights in the SFAR and commercial river tours along the Colorado River result in emissions occurring in six other grid cells.

Emissions within the Commission inventory were gridded based on areal apportionment using geographic information system (GIS) technology. For example, if 5% of a county's area lies within a grid cell, it was assumed that 5% of the county's emissions occurred in that cell. At the request of the Commission Modeling and Emissions subcommittees, we gridded the micro inventory and regredded the Commission's inventory for Coconino County by taking into account urban versus rural land use patterns. The spatial surrogates used for regressing consisted of the 1990 Census data, the spatial distribution of highways in Coconino County, and the fraction of each grid cell in the county. Table 9 compares emissions for grid cell (33,21) for these three alternative gridded inventories.

The emission estimates presented in Table 9 are for a grid cell with an area of approximately 2,500 km² (50 km by 50 km). Much of the emissions in the Park, however, occur in or near Grand Canyon Village, the Grand Canyon Airport and in a narrow strip along the East Rim Drive from Grand Canyon Village to Desert View. Table 10 presents a comparison of the estimated emissions density from the Commission inventory for grid cell (33,21) and for the small area (approximately 330 km²) along the South Rim where much of the emissions in the Park occur. The micro inventory densities in Table 10 were computed from the emission estimates from Table 1 for the South Rim and that portion of aircraft emissions due to landings and takeoffs (LTOs) from Grand Canyon Airport. Emissions from cruising aircraft and recreational boating are not included in the micro inventory densities shown in Table 10.

Even without cruising aircraft or recreational boating emissions, the micro inventory densities are approximately a factor of 10 larger than the Commission emission densities for grid cell (33,21). The difference in emission density could potentially be significant when input to a visibility model. However, the current visibility model being used by the Commission to assess regional visibility impacts has a relatively coarse grid resolution of 50 km. Therefore, the higher emission densities noted in the Park cannot be accounted for in the current model. Additional model development work to enhance the spatial resolution of the Commission's model is required for use of the micro inventory for visibility modeling.

Gridded emissions for the 27 Commission grid cells falling in Coconino County are given in Table 11. Table 12 presents the southwest corner latitude and longitude for each grid cell in a 7 (east-west) by 6 (north-south) rectangular grid covering northern Arizona. The Coconino County grid cells in Table 11 are a subset of that portion of the Commission grid for northern Arizona given in Table 12.

5.0 ACKNOWLEDGMENT

We wish to thank Mr. Carl Bowman and Ms. Cathy Rhodes of the NPS for their collection of all the activity data for this micro inventory. The inventory would not have been possible without their enthusiastic help. In particular, we appreciate the contribution of Mr. Bowman who, in a very short period of time, identified and contacted the many sources of data and followed-through on the data collection.

Table 2

Comparison of Emissions (Tons/Year) from the Grand Canyon Visibility Transport Commission Inventory for Coconino County, Arizona, and the MicroInventory for Grand Canyon National Park

ASCT	Source	1993 Grand Canyon NP				1990 Coconino County ¹			
		SO ₂	NO _x	TSP ²	VOC	SO ₂	NO _x	TSP ¹	VOC
2103004000	Commercial/Institutional Fuel Combustion, Boilers & IC Engines - Distillate Oil	14	12	0.7	0.7	12	5.7	0.6	0.2
2104007000	Residential Fuel Combustion, All Combustors - LPG Gas		0.1			0			
2104008000	Residential Wood Combustion	0.1	0.7	7.8 ³	6.5	10	66	980	410
2201000000	Highway Vehicles - Gasoline	6.2	150	2.3 ⁴	160	130	3,140	480	4,160
2230000000	Highway Vehicles - Diesel	28	170	16 ⁴	39	470	2,670	76	340
2275000000	Aircraft	6.5	84	17	69	0.1	1.3	0.2	3.8
2282000000	Recreational Boating - Gasoline	2.9	8.6	47	870	0	0.3	0	3.6
2285002000	Trains - Diesel	1.4	2.5	0.1	0.1	30	410	18	19
2294000000	Road Dust from Paved Roads				1950			15,000	
2302002000	Commercial Charboiling			0.6 ⁴			0		
2401000000	Solvents from Surface Coating					15			220
2461021000	Road Paving - Cutback Asphalt					16			78
2465000000	Consumer Solvents					15			150

Table 2
(Continued)

ASCT	Source	1993 Grand Canyon NP				1990 Coconino County ¹			
		SO _x	NO _x	TSP ²	VOC	SO ₂	NO _x	TSP ⁴	VOC
2501000000	Storage Tanks - Gasoline and Diesel				19				1280
2620000000	Waste Disposal - Landfills				< 0.01				0
2810001000	Forest Wildfires	NE ⁵	NE	NE	NE	NE	NE	NE	NE
2810015000	Prescribed Burning	NE	NE	NE	NE	NE	NE	NE	NE
2810025000	Charcoal Combustion (includes GCNP wood campfires)	0.02	0.2	2.0 ³	1.5	0	0	0	0
Totals ⁶		59	420	2,000	1,200	650	6,300	16,600	6,700
									(10/06/94)

¹Includes source emissions in Coconino County from the Commission Inventory

²All particulate matter emissions are expressed as total particulate except where noted.

³PM₁₀

⁴PM_{2.5}

⁵NE - No estimate. Given the sporadic nature of fires, a mean yearly value is not an appropriate measure of emissions from wildfires and prescribed burning

⁶All totals rounded to two significant figures

Description of Emission Sources Inventoried in Grand Canyon National Park¹

Source Type	Discussion
Commercial/Institutional Fuel Combustion in Boilers and Internal Combustion Engines	The NPS and concessionaires operate approximately 170 boilers, heating furnaces, generators, and commercial and residential water heaters in GCNP. Approximately 1.25 million gallons of fuel (propane, diesel, and fuel oil) were combusted in these devices. Emissions were estimated using AP-42 emission and speciation factors and activity data provided by the NPS.
Residential LPG Gas Combustion	Liquid propane gas sales on the South Rim were approximately 10,000 gallons. Most of the LPG was combusted in visitor recreational vehicle generators and gas grills. North Rim usage was estimated from South Rim usage based upon the percentage of North Rim to total park visitation (approximately 10%). Emissions were estimated using AP-42 emission and speciation factors and activity data provided by the NPS.
Residential Wood Stoves	Housing records indicate there are 135 residential woodstoves and fireplaces in government and concessionaire housing at the South Rim of GCNP. U.S. Forest Service wood cutting permits for individuals with a Grand Canyon Village ZIP code (86023) listed 348 cords of wood cut in 1993. Fred Harvey Company consumed an additional 100 cords in woodstoves and fireplaces in its hotel and lodges. Average wood consumption per household was estimated from the census and U.S.F.S data. Emission factors were obtained from AP-42.
Highway Vehicles - Gasoline	In 1993, over 1.4 million vehicles entered GCNP at South Rim and over 270,000 vehicles entered the North Rim. Average emission factors were developed separately for visitor vehicles (both gasoline and diesel) and NPS gasoline vehicles. Vehicle speciation was based upon a limited survey of vehicles entering the South Entrance and the NPS vehicle inventory. Vehicle total VMT was estimated from data provided by the NPS.

Table 3

(Continued)

Source Type	Discussion
Highway Vehicles - Diesel	<p>In 1993, over 28,000 busses entered the South Rim and 550 entered the North Rim. In addition, there is a large diesel-fueled shuttle bus fleet (NPS and concessionaire) at the South Rim. Average emission factors were developed separately for commercial diesel buses and NPS diesel vehicles. Vehicle speciation was based upon a limited survey of vehicles entering the South Entrance and the NPS vehicle inventory. Vehicle total VMT was estimated from data provided by the NPS.</p>
Commercial Sightseeing Aircraft Tours	<p>Commercial aircraft sightseeing tours are very popular at the South Rim with approximately 770 flights on an average summer day and an estimated 163,000 flights per year. Most of these flights originate at the Grand Canyon airport. Flight level for these flights is less than 2,000 feet above the South Rim elevation. Flight activity data for an average summer day was obtained from the NPS. These data were annualized based upon NPS seasonal visitation data. Emissions were estimated for helicopters, single and twin engine aircraft (gasoline-powered), and twin engine turboprop aircraft. Emission factors were obtained from AP-42 and other U.S. EPA publications.</p>
Recreational Vessels - Gasoline	<p>There were 662 commercial and private sightseeing boat trips down the Colorado River through the Grand Canyon. The number of hours outboard engines were operating was approximately 60,000. The average engine is a 2-stroke engine of approximately 30 horsepower. Emissions were estimated from the NPS operation data, emission factors from AP-42 (assumed 2-stroke engine) and an assumed load factor of 50%.</p>
Trains - Diesel	<p>The Grand Canyon Railway operated approximately 300 round-trips per day into GCNP. The train is pulled by an oil-fired steam engine. On approximately 15% of the trips, a diesel-engine is added to the train. Emissions were estimated from operation data provided by the NPS from data submitted by Grand Canyon Railway Company and AP-42 emission factors.</p>

Table 3
(Continued)

Source Type	Discussion
Road Dust from Paved Roads	Traffic volume in GCNP was approximately 65 million vehicle miles traveled. The U.S. EPA PART5 model was used to estimate road dust emissions based upon the vehicle activity data used to estimate direct motor vehicle emissions.
Commercial Charbroiling	The concessionaire for the South Rim estimated that approximately 50,000 pounds of beef was prepared in 1993, of which approximately 75% (38,000 pounds) was charbroiled. Emissions were estimated from the amount of meat grilled times an emissions factor from Cass, et al., 1991. <i>Env. Sci Tech</i> , Vol 25, No. 4. North Rim emissions were estimated from the South Rim emissions based upon proportional visitation.
Solvents from Surface Coating	The NPS maintenance shop estimated that approximately 1,050 gallons of interior and exterior paint used on the South Rim and 800 gallons of road striping paint were used throughout the park. Concessionaire usage was estimated by the NPS to be approximately double NPS usage. North Rim paint usage was estimated from the South Rim usage based upon proportional visitation. Total park-wide paint usage is estimated to be approximately 3,950 gallons per year. Emissions were estimated from the NPS activity data and emission factors from AP-42.
Road Paving - Cutback Asphalt	Approximately 70 tons of cutback asphalt were used in road maintenance and paving on the South Rim in 1993. North Rim usage is estimated to be approximately 10% of South Rim usage. Emissions were estimated from the NPS activity data and AP-42 emission factors.
Consumer Solvents	There are approximately 2,500 full time residents in GCNP. In addition, there are approximately 800 summer employees, and an average of 1,700 persons per night staying in the lodges and hotels. This is equivalent to a city of approximately 5,000 persons who will use products containing consumer solvents such as toiletries and household cleaning products. Emission were estimated based upon the effective population and AP-42 emission factors.

Table 3

(Continued)

Source Type	Discussion
Storage Tanks - Gasoline and Diesel	Approximately 1.9 million gallons of gasoline were stored and dispensed in GCNP in 1993, a source of evaporative VOC emissions. Evaporative emissions of diesel are small. Emissions were estimated from the NPS activity data and AP-42 emission factors.
Waste Disposal - Landfills	One landfill is located at GCNP on the South Rim. An average of 4,500 tons per day of solid waste is landfilled which is covered daily with a clay/topsoil cap. Emissions were estimated using U.S. EPA methodology and determined to be negligible.
Forest Fires	Estimates of forest fire (wildfire) emissions were obtained from the USDA Forest Service (Peter Lahn).
Prescribed Burning	Estimates of prescribed burning emissions were estimated by Radian using USDA Forest Service methodology from Peterson and Ward (USDA Forest Service, Pacific Northwest Research Station, 1993) based upon data provided by Peter Lahn.
Charcoal Combustion (includes GCNP wood campfires and concessionaire fires)	Concessionaire sales of charcoal are approximately 40,000 pounds per year at the South Rim and 4,000 pounds (10% of South Rim sales) on the North Rim. Charcoal is primarily a source of VOC emissions due to the starter used to ignite the charcoal. Also included in this category is an estimated 27,000 pounds of wood combustion on river trips in the winter, and approximately 28,000 pounds of wood sold by concessionaires to visitors for campfires. Emissions were estimated from the activity data provided by the NPS and AP-42 emission factors.

All activity data presented in this table are for 1993.

(Revised 08/19/94)

Table 4

Insignificant Emission Sources Not Inventoried in Grand Canyon National Park

Source Type	Discussion	Disposition
Refuse incinerator	A refuse incinerator is located at the medical clinic. It was last used in 1991. When in use, the incinerator is operated only a few hours per year.	No activity in 1993 and none expected in the future.
Sandblasting	Decorative metal work and other small objects are occasionally sandblasted. This is a very intermittent, small source.	Insignificant source
Wastewater treatment sludge	Sludge is composted. Due to moisture content when handled, very low particulate emissions are expected.	Insignificant source
Asphalt roofing	No asphalt roofing occurred in 1993. No NPS buildings retain asphalt roofs. Concessionaire asphalt roofs are scheduled to be replaced with non-asphalt roofs.	No activity in 1993 and none expected in the future.
Emergency generators	There are 3 emergency generators on the South Rim. These generators are tested approximately monthly.	Insignificant source
Livestock corral	There are approximately 250 NPS and concessionaire mules, burros, and horses in GCNP. Particulate emissions from the corrals are small.	Insignificant source
Trail maintenance	All trail maintenance in the canyon is performed by hand	Insignificant source
Off-road vehicles	Visitor off-road vehicles are not allowed in GCNP. NPS off-road usage is small.	Insignificant source
Snow mobiles	Only a few snow mobiles are in use on the North Rim by maintenance personnel. The North Rim is closed to visitors in the winter.	Insignificant source
Unpaved road dust	There are very few unpaved roads in GCNP on which visitors have access. Annual VMT is very small.	Insignificant source
Structure Fires	Few structure fires occur on GCNP and they are very episodic.	Probable insignificant source

Table 5

**Grand Canyon National Park Wildfire Emission Estimates
for Fires Greater than 100 Acres**

Year	Number of Fires	Acreage	Annual Emissions (tons/year)					
			PM _{2.5}	EC _{2.5}	OC _{2.5}	VOC	NO _x	CO
1986	2	500	40	2.1	22	21	31	450
1987	5	2,425	160	8.3	86	80	120	1,700
1988	3	3,541	240	10	120	120	180	2,600
1989	3	5,060	400	30	240	210	260	3,800
1990	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0

Table 6

Grand Canyon National Park Prescribed Fire Emission Estimates

Year	Acreage	Annual Emissions (tons/year)				
		PM _{2.5}	EC _{2.5}	OC _{2.5}	VOC	CO
1989	90	4.3	0.4	2.1	2.3	NA ¹
1990	180	8.0	0.7	4.0	3.7	0.1
1991	0	0	0	0	0	0
1992	2,297	110	9.1	53	50	1.3
1993	1,351	75	6.7	37	34	0.9

¹NA - Not Available

Table 7

Potential Double Counting of Emission Sources between the Grand Canyon Visibility Transport Commission Inventory and the Grand Canyon National Park Micro Inventory

GCNP Source Type	Basis for Emission Estimates in the Commission Inventory	Conclusion
Commercial/Institutional Fuel Combustion in Boilers and Internal Combustion Engines	County-wide fuel usage and emission estimates in the Commission inventory are based upon estimated county-wide number of institutions (i.e., number of hotel rooms, hospital rooms, etc.) and employment in specific SIC source categories and then normalized by statewide commercial fuel sales.	Likely double counting
Residential LPG Gas Combustion	County level LPG emissions in the Commission inventory are estimated using a model of LPG consumption based upon county-specific degree-day and housing statistics, and normalized for county sales as needed.	Likely double counting
Residential Wood Combustion (RWC) (including fireplaces and wood stoves in Fred Harvey lodges).	County level RWC emissions in the Commission inventory are estimated from statewide wood consumption estimates developed by DOE and allocated to the county level on the basis of housing statistics using wood as the primary heating fuel. These emissions likely do not account for wood combustion in the guest lodges. Lodge RWC emissions account for approximately 25% of the GCNP micro inventory RWC emissions.	Likely double counting of emissions from housing units only.
Highway Vehicles - Gasoline	The motor vehicle estimates for Coconino County contained in the Commission Inventory are ultimately based upon traffic survey data produced by Arizona Department of Transportation. An unknown portion of the VMT data in the Grand Canyon micro inventory will contain duplicate that in the ADOT data, and hence, in the Commission Inventory.	Some double counting likely.
Highway Vehicles - Diesel	The motor vehicle estimates for Coconino County contained in the Commission Inventory are ultimately based upon traffic survey data produced by Arizona Department of Transportation. An unknown portion of the VMT data in the Grand Canyon micro inventory will contain duplicate that in the ADOT data, and hence, in the Commission Inventory.	Some double counting likely.
Commercial Sightseeing Aircraft Tours	Estimates of emissions from commercial (tour company) landings and takeoffs (LTOs) from the Grand Canyon airport are probably contained in the Commission inventory for Coconino County. Emissions for aircraft flights over Grand Canyon National Park (excluding LTOs) are not contained in the Commission inventory. The LTO emissions for commercial operations at Grand Canyon airport are approximately 10% of the estimated aircraft emissions in the micro inventory.	Likely double counting of LTO emissions only.

Table 7
(Continued)

GCNP Source Type	Basis for Emission Estimates in the Commission Inventory	Conclusion
Recreational Vessels - Gasoline	Recreational vessel emissions in the Commission inventory were calculated for specific geographic area based and extrapolated based upon population. The Commission estimates are probably biased low because of the simplistic extrapolation technique used in the U.S. EPA Interim inventory upon which the Commission inventory is based.	Potential double counting
Trains - Diesel	Commission railroad emissions are allocated to the county level based upon population and statewide distillate oil use by railroads as reported in a DOE report on petroleum marketing. For the Interim inventory, emissions were recalculated and extrapolated from specific geographic areas based upon population. Because of its small size, it is uncertain whether the Grand Canyon Railway Company diesel fuel usage is included in survey data used to develop the Interim inventory estimates.	Potential double counting
Road Dust from Paved Roads	The Grand Canyon micro inventory estimates of road dust were estimated using the newly released U.S. EPA PART5 model. The Commission Inventory contains some estimates of entrained road dust emissions. The amount of duplication is unknown.	Some double counting likely.
Commercial Charbroiling	Charbroiling emissions are not included in the Commission inventory for Coconino County.	No double counting
Solvents from Surface Coating	The Commission inventory estimate for Coconino County is based upon a national estimate of surface coating solvent usage allocated by population to the state and county level.	Likely double counting
Road Paving - Cutback Asphalt	County emissions are estimated from statewide cutback asphalt usage allocated to the county level based on employment in SIC category 1611.	Likely double counting
Consumer and Commercial Solvents	Commission emissions for this category are estimated from national estimates of consumer solvent usage allocated to the state and county level on the basis of population. In addition to estimates based upon residential population, the GCNP micro inventory contains additional consumer solvent emissions estimates allocated to visitors. These additional emission estimates are for toiletries and other consumer items used by GCNP visitors that stay overnight in the hotel and lodges in GCNP and are approximately 30% of the consumer solvent category estimates.	Likely double counting for permanent resident park population.

Table 7
(Continued)

GCNP Source Type	Basis for Emission Estimates in the Commission Inventory	Conclusion
Storage Tanks - Gasoline and Diesel	If direct county gasoline sales information is available, these data were used directly to estimate storage tank emissions by county. For counties without county sales data, state-wide retail gasoline sales are used to allocate emissions to the county level based upon the county's estimated proportion of statewide sales.	Likely double counting
Waste Disposal - Landfills	Estimates of emissions from solid waste landfills are not contained in the Commission inventory for Coconino County.	No double counting
Forest Fires	Emission estimates for forest fires (wildfires) are not contained in the Commission inventory for Coconino County.	No double counting
Prescribed Burning	Emission estimates for prescribed burning are not contained in the Commission inventory for Coconino County.	No double counting
Charcoal Combustion (includes GCNP wood and charcoal campfires and river trip campfires)	Estimates of emissions from charcoal and wood campfires are not contained in the Commission inventory.	No double counting

Table 8

Grand Canyon National Park Micro Inventory Gridded Emissions, 1993

Grid Cell (X,Y)	Average Annual Emissions (ton/year)								
	SO _x	NO _x	CO	PM _{2.5}	OC _{2.5}	EC _{2.5}	SO ₄	TSP	VOC
34,22	0.71	2.15	400	5.32	2.66	1.20	0.19	11.8	217
32,22	0.71	2.15	400	5.32	2.66	1.20	0.19	11.8	217
34,21	0.71	2.15	400	5.32	2.66	1.20	0.19	11.8	217
33,21	55.6	398	2,980	1,980	97.8	15.2	1.23	2,000	547
32,21	0.62	9.69	163	0.88	0.09	0.24	0.0	2.26	3.86
31,21	0.13	2.02	36.0	0.19	0.02	0.50	0.0	0.49	0.85
30,21	0.28	4.56	327	0.36	0.04	0.10	0.0	0.93	4.27
Total ^{a,b}	59	420	4,700	2,000	110	19	1.8	2,000	1,200

^aEmission estimates do not include wildfire or prescribed fire emissions.

^bEmission totals rounded to two significant figures.

Table 9
Comparison of Inventory Estimates for the Grid Cell (33,21)
Containing Grand Canyon Village

Inventory	Average Annual Emissions for Grid Cell (33,21) (ton/year)*								
	SO _x	NO _x	CO	PM _{2.5}	OC _{2.5}	EC _{2.5}	SO ₄	TSP	VOC
Micro inventory ^b	56	400	3,000	2,000	98	15	1.2	2,000 ^c	550
Commission Inventory ^c	38	160	770	1,400	52	24	-	12,000	220
Regridded Commission Inventory ^d	19	230	1,300	810	26	11	-	9,600	210

*All emission estimates rounded to two significant figures.

^bMicro inventory for Grand Canyon National Park for 1993. Excludes wildfires and prescribed burns.

^cGrand Canyon Visibility Transport Commission Inventory for 1990.

^dRegridding of the Commission Inventory during micro inventory development.

^eLower limit since some particulate matter estimated as PM_{2.5} or PM₁₀

Table 10

**Comparison of Estimated Emission Densities for Emissions
from Grand Canyon Village**

Inventory	Average Annual Estimated Emissions Density (kg/year-km ²) ^a									
	SO _x	NO _x	CO	PM _{2.5}	OC _{2.5}	EC _{2.5}	SO ₄	TSP	VOC	
Micro-inventory ^b for Grand Canyon Village	120	840	4,900	5,300	250	33	2.7	5,300 ^c	680	
Commission Inventory ^c Grid Cell (33,21)	14	58	280	520	19	8.6	-	4,400	79	
Regridded Commission Inventory ^d Grid Cell (33,21)	7.0	82	480	290	9.5	4.0	-	3,500	76	

^aAll emission density estimates rounded to two significant figures.

^bMicro inventory for Grand Canyon National Park (GCNP) for 1993. Excludes wildfires and prescribed burns.

^cGrand Canyon Visibility Transport Commission Inventory for 1990.

^dRegridding of the Commission Inventory during GCNP micro inventory development.

^eLower limit since some particulate matter estimated as PM_{2.5} or PM₁₀

Table 11

**Gridded Area Source Emissions for Coconino County, Arizona, for 1990
from the Grand Canyon Visibility Transport Commission Inventory**

Grid Cell		Area Source Gridded Emissions (Tons/Year)							
X	Y	TSP	PM _{2.5}	EC _{2.5}	OC _{2.5}	SO _x	NO _x	VOC	CO
36	18	3,760	106	1.7	4.1	1.0	15	18	84
36	19	4,708	368	2.6	7.9	8.1	86	68	501
36	20	3,008	85	1.4	3.3	0.8	12	15	68
36	21	2,256	63	1.0	2.5	0.6	9	11	51
36	22	1,504	42	0.7	1.7	0.4	6	7	34
35	18	6,015	169	2.7	6.6	1.6	24	29	135
35	19	9,417	736	5.3	15.8	16.2	171	135	1,003
35	20	8,255	425	7.3	16.5	8.4	107	112	616
35	21	9,764	843	9.1	23.0	19.8	221	193	1,289
35	22	13,104	1,841	36.3	76.2	51.6	638	640	3,684
35	23	8,126	387	6.4	14.7	7.2	92	96	528
34	19	54,536	14,265	269.6	564.3	427.7	5,176	5,047	29,929
34	20	10,725	1,117	13.0	31.7	27.9	314	276	1,825
34	21	9,017	631	6.7	17.3	13.7	154	136	898
34	22	8,743	550	4.6	13.2	11.2	121	100	707
34	23	13,650	1,983	34.2	73.8	55.0	660	637	3,819
33	19	6,335	847	13.7	30.2	23.0	273	260	1,583
33	20	8,498	482	4.4	12.2	9.3	103	88	599
33	21	9,619	809	11.1	26.0	19.3	226	210	1,309
33	22	8,498	482	4.4	12.2	9.3	103	88	599
33	23	9,444	758	9.8	23.5	17.7	205	188	1,190
32	20	8,009	347	3.9	10.2	5.6	66	62	384
32	21	7,519	212	3.4	8.3	1.9	30	37	169
32	22	3,868	141	3.4	7.2	2.2	34	42	194
32	23	3,252	152	1.6	4.3	2.6	30	27	175
31	20	2,256	63	1.0	2.5	0.6	9	11	51
31	21	3,008	85	1.4	3.3	0.8	12	15	68
Total		236,893	27,989	461	1,013	743	8,896	8,547	51,492

Table 12

**Grid Cell Southwest Corner Coordinates for Northern Arizona
from the Grand Canyon Visibility Transport Commission Inventory**

Number	Cell X	Cell Y	West Long	North Lat
1	37	18	110.49	34.24
2	36	18	111.02	34.28
3	35	18	111.56	34.32
4	34	18	112.10	34.36
5	33	18	112.65	34.40
6	32	18	113.19	34.43
7	31	18	113.73	34.46
8	37	19	110.43	34.69
9	36	19	110.97	34.73
10	35	19	111.52	34.77
11	34	19	112.06	34.81
12	33	19	112.60	34.84
13	32	19	113.15	34.88
14	31	19	113.70	34.91
15	37	20	110.38	35.13
16	36	20	110.92	35.17
17	35	20	111.47	35.22
18	34	20	112.01	35.25
19	33	20	112.56	35.29
20	32	20	113.11	35.32
21	31	20	113.66	35.36
22	37	21	110.32	35.58
23	36	21	110.87	35.62
24	35	21	111.42	35.66
25	34	21	111.97	35.70
26	33	21	112.52	35.74
27	32	21	113.07	35.77
28	31	21	113.62	35.80

Table 12

(Continued)

Number	Cell X	Cell Y	West Long	North Lat
29	37	22	110.27	36.02
30	36	22	110.82	36.07
31	35	22	111.37	36.11
32	34	22	111.92	36.15
33	33	22	112.48	36.18
34	32	22	113.03	36.22
35	31	22	113.59	36.25
36	37	23	110.21	36.47
37	36	23	110.76	36.51
38	35	23	111.32	36.56
39	34	23	111.87	36.59
40	33	23	112.43	36.63
41	32	23	112.99	36.67
42	31	23	113.55	36.70

*Grand Canyon National Park (South Rim) contained in this grid cell.

APPENDIX A

**DESCRIPTION OF WILDFIRE AND PRESCRIBED
BURN EMISSIONS ESTIMATION METHODOLOGY**

APPENDIX A

WILDLAND BURNING

While the National Park Service was responsible for developing the activity data used for the micro inventory calculations, a different approach was taken for wild and prescribe fires (i.e., wildland burning). Emissions for wildfires in the Grand Canyon National Park micro inventory were developed by the United States Department of Agriculture (USDA) Forest Service as part of the inventory preparation work for the overall inventory needed to support the activities of the Commission (Lahm, 1994a). Radian developed emission estimates for prescribed fire in the Park from the data presented in Peterson and Ward (1993). These data were also developed by the Forest Service, but on a national scale.

The Forest Service emission estimating technique for wildland burning is based on empirical emission factors and the mass of fuel consumed. Fuel consumption is a function of preburn fuel loading, percent fuel consumption, and area burned. Fuel loading in the Forest Service emission calculations is determined through the use of fuel models. There are 20 different fuel models used to describe the type and quantity of biomass that may be consumed in a wild or prescribed fire (see Anderson, 1982). Thus far, the Forest Service has provided little information documenting the data used to develop the fuel loading values. Consequently, we are unable to provide a detailed emission estimating technique for wildland burning. The Park micro inventory, therefore, relies extensively on the emission calculation work previously performed by the Forest Service.

Wildland burning can be a significant source of fine particulate matter. The particulate emitted from a fire also contain elemental and organic carbon, two key species in the analysis of visibility impairment on the Colorado Plateau. Current wildland burning emission estimates for the Park are presented below.

It should be noted that wildfires are highly episodic in nature compared to other categories such as mobile sources that remain relatively constant from day-to-day. For example, there were no wildfires greater than 100 acres in the Park for the years 1990 to

1992. However, in 1989, there were three fires that were the dominant emissions source of EC_{2.5} and OC_{2.5} in the Park. Therefore, on an episodic basis, wildfire can be a dominate source of emissions in the Park.

The number of acres treated in the Park with prescribed fire was also obtained from the Forest Service. The available data covers the period 1989 to 1993. As with wildfires, prescribed fire activity is highly variable from year to year.

The methodology for estimating emissions for prescribed fires was obtained from Peterson and Ward (1993). The emission estimates for 1990 through 1993 were developed by Radian using emission factors extracted from the work of Peterson and Ward (1993) and combined with activity data obtained from Lahm (1994b). The emission factors represent average, national conditions by fuel model. Site-specific conditions at the Park could be significantly different, thus introducing significant uncertainty into the emission estimates. Prescribed fire EC_{2.5} and OC_{2.5} emissions for the Park tend to be smaller than the wildfire emission estimates.

References

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APPENDIX B

Detailed Emission Summaries